SNS Front-end Diagnostics, An introduction

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SNS Diagnostics

Efficient operation of complex accelerators depends very much on the measurement of the relevant beam parameters within a wide range of intensities.

Therefore the development of versatile measurement techniques become essential.

For example:

(1) Remotely controllable devices.
(2) High precision measurements.
(3) Monitoring disturbances to the beam during measurements.
(4) bi-directional feedback.
(5) Error handling and status checking.
(6) Monitoring environment, such as losses and their effects on your Measurements (position).
(7) Common Sense

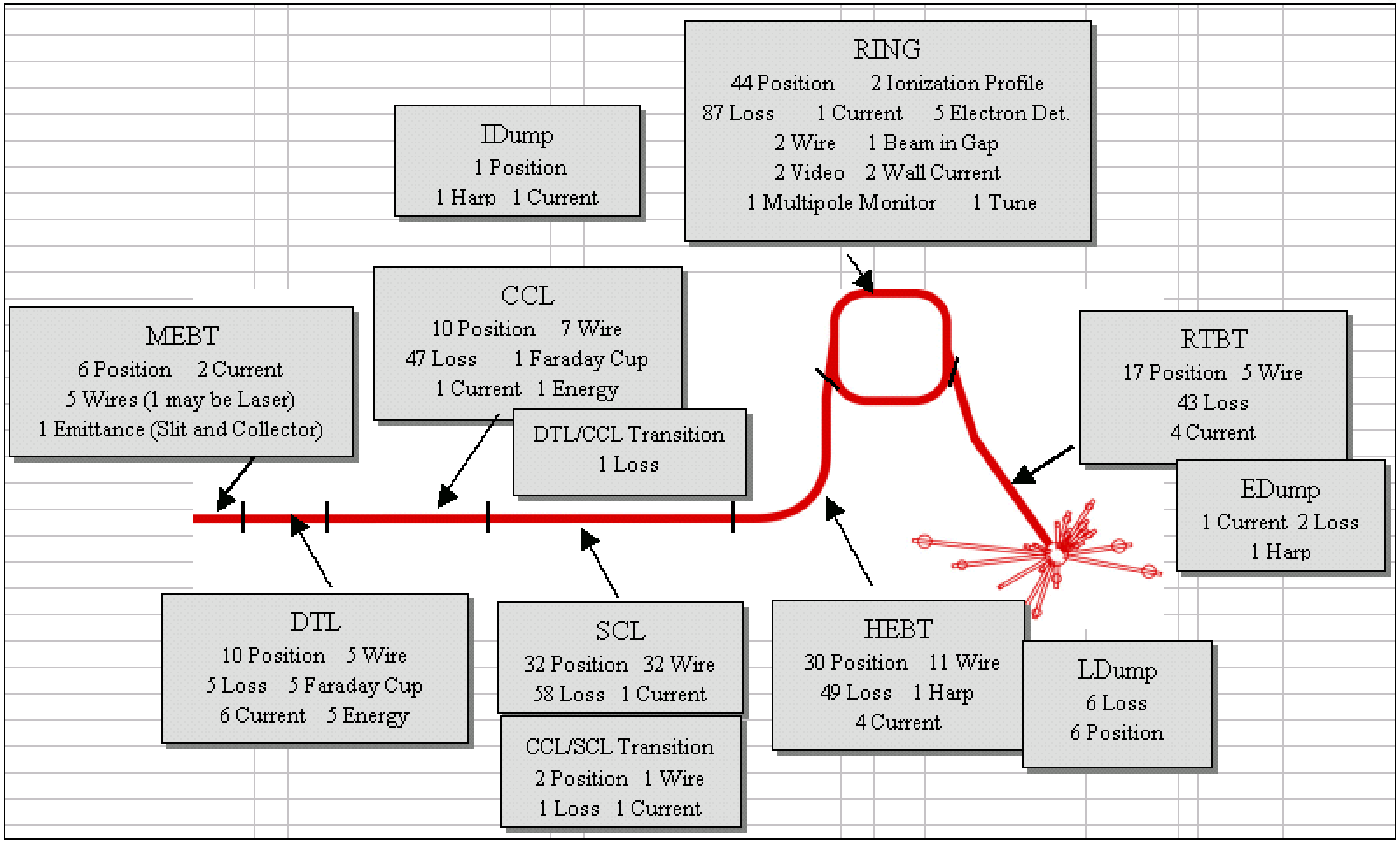
Last but not least elements of a diagnostic system should be standardized as much as possible.

MEBT Diagnostics

The main beam parameters which have to be measured for the control of an accelerator are:

1) Beam Profile– intensity distribution over both transverse coordinates
2) Beam Current
3) Beam Position
4) Beam energy
5) Energy spread
6) Shape of the bunch, which means intensity distribution versus time.
7) Position of the bunches versus an rf-reference signal
8) Beam emittance in the transverse and the longitudinal phase space.

MEBT Diagnostics



5 WS, 6 BPMs, 2 BCMs, 1 Emittance device, 1 Laser-wire And Fast Faraday Cup, Beam Dump (Faraday Cup).

MEBT Diagnostics, Wire Scanners

Overview

- PC-based, data acquisition and control of one wire scanner
- Windows 2000 PC operating system
- LabVIEW stand-alone run-time versions running on each PC
- National Instruments data acquisition card, PCI-6110
- National Instruments motion control card, PCI-7344
- National Instruments stepper motor/driver unit, MID-7602/4
- Each a stand-alone system with links to EPICs for remote control and monitoring.
- Built-in-test (BIT) features. Verify each electronic channel, gain, ADCs and triggering.
- Front-panel indicators on the 1U-high electronics chassis
- Detection of wire or cabling fault (open circuit)

All WS Specification Highlights

ITEM		
Macro Rep. Rate	1	Hz
Macro pulse width	50-100	usec
# of wire channels	3	
Channel Sample Rate	up to 5.0	MSa/sec
Coupling	AC	
Gain Settings	3	~ 15 dB steps
High-voltage Bias	0 to -100	VDC
Bipolar Bias	yes	plug-on card
Channel Bandwidth	45	kHz
Max. Input Current	15	mA
Min. Input Current	< 0.1	uA
Electronics Noise Floor	< 1 LSB	< 4.88 mV any gain
Input Signal Polarity	bipolar	
Max. Input Current High Gain	30 +/-0.007	uA (10Vdc FS)
Max. Input Current Med. Gain	250 +/-0.06	uA (10Vdc FS)
Max. Input Current Low Gain	2400 +/- 0.5	uA (10Vdc FS)
Linearity	< 0.1	%
LVDT Position Resolution	+/- 0.25	mill, assumes 2" travel, 12-bit ADC, +/- 10 VDC signal

Development

Actuator from BNL

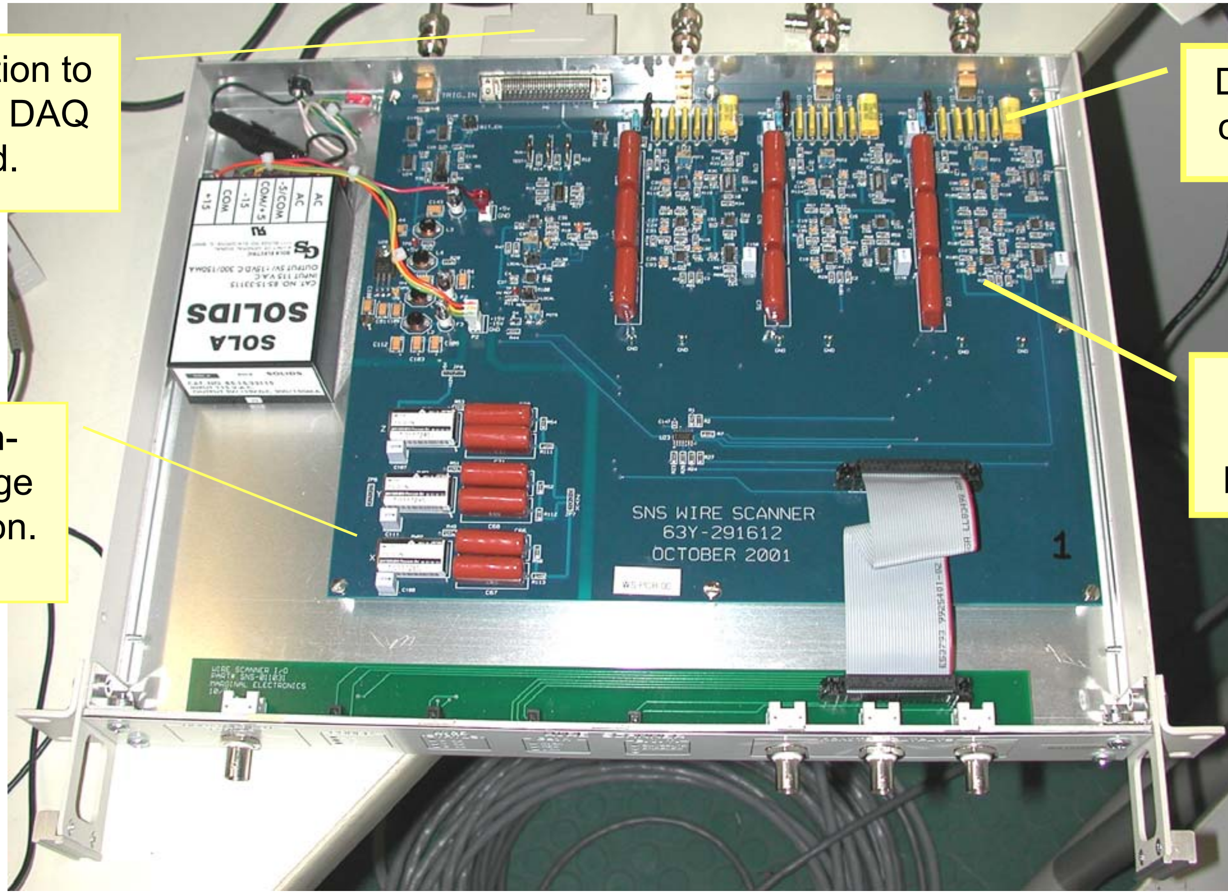
Industrial PC used for development and prod. systems.

Stepper motor driver

Electronics Chassis Top

Connection to host PC DAQ card.

High-voltage section.



Decoupling capacitors.

One of three WS channels. Each identical.

Picture of the 1U-high, electronics chassis.

Electronics Chassis Front

Timing TTL monitor signal

Status indicators: power, wire, gain, B.I.T.

WS channel monitor ports

Front panel view of the 1U-high electronics chassis. LEDs indicate power, wire status, gain setting, and B.I.T. state. BNCs allow the user to monitor the analog voltage of each of the three channels, X, Y, Z as well as the timing source.

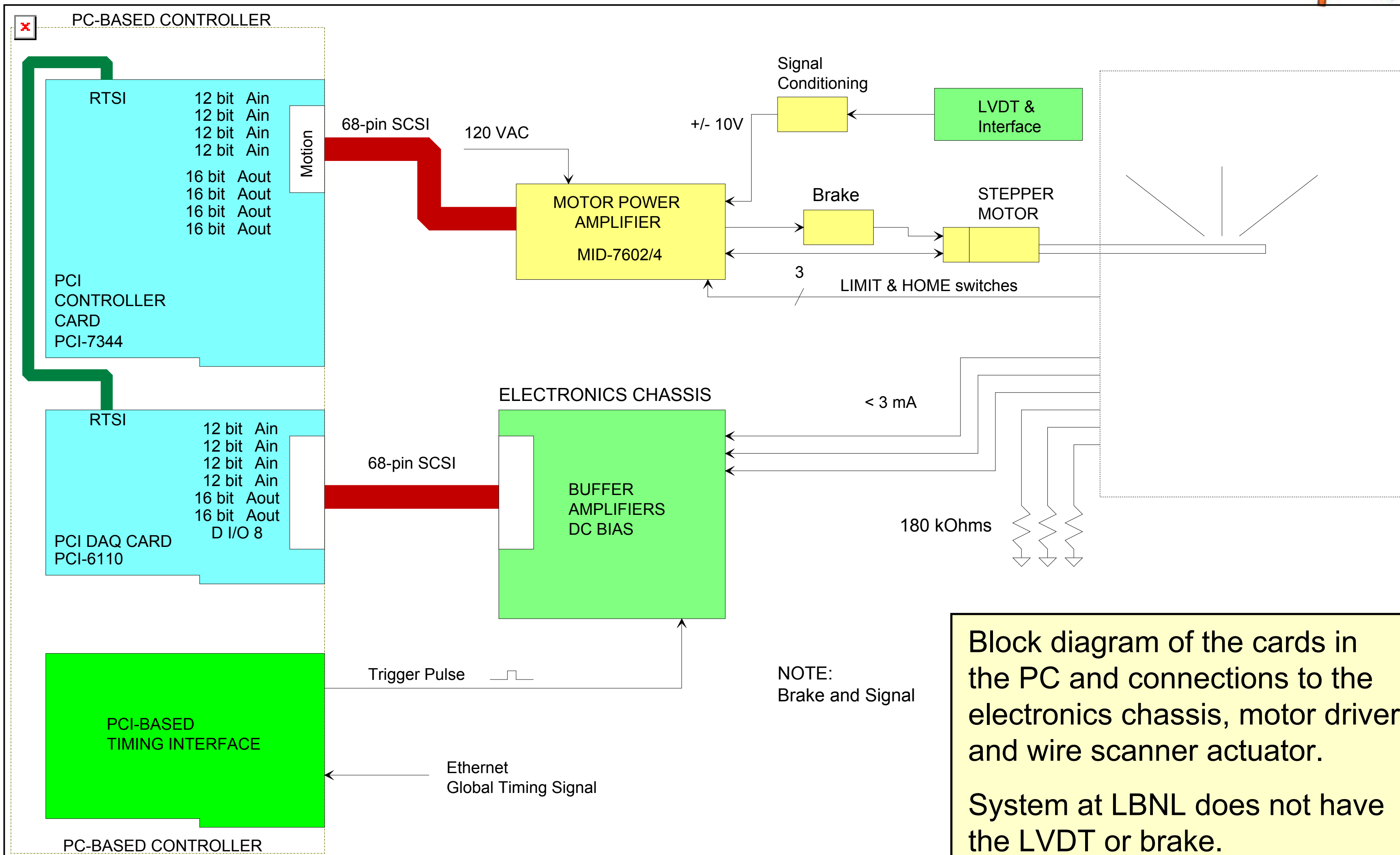
System Integration Results

Prototype actuator from BNL allowed LANL to test, in our lab, the entire system from the actuator through the preamplifiers to the sampling ADCs and examine signal level and control features.

The BNL actuator and cables worked perfectly with the LANL controls.

Thanks BNL!

Block Diagram

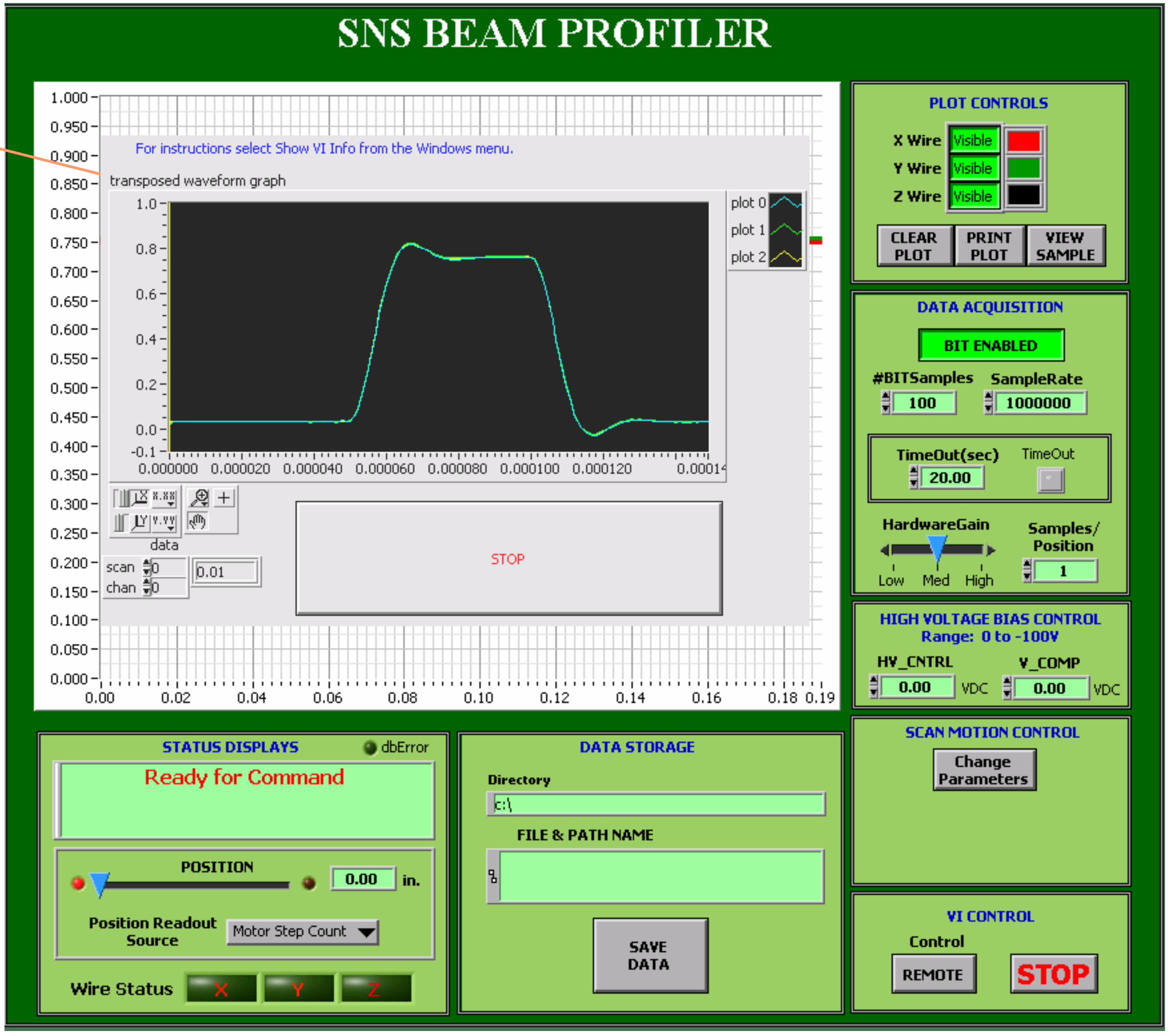


Block diagram of the cards in the PC and connections to the electronics chassis, motor driver and wire scanner actuator.

System at LBNL does not have the LVDT or brake.

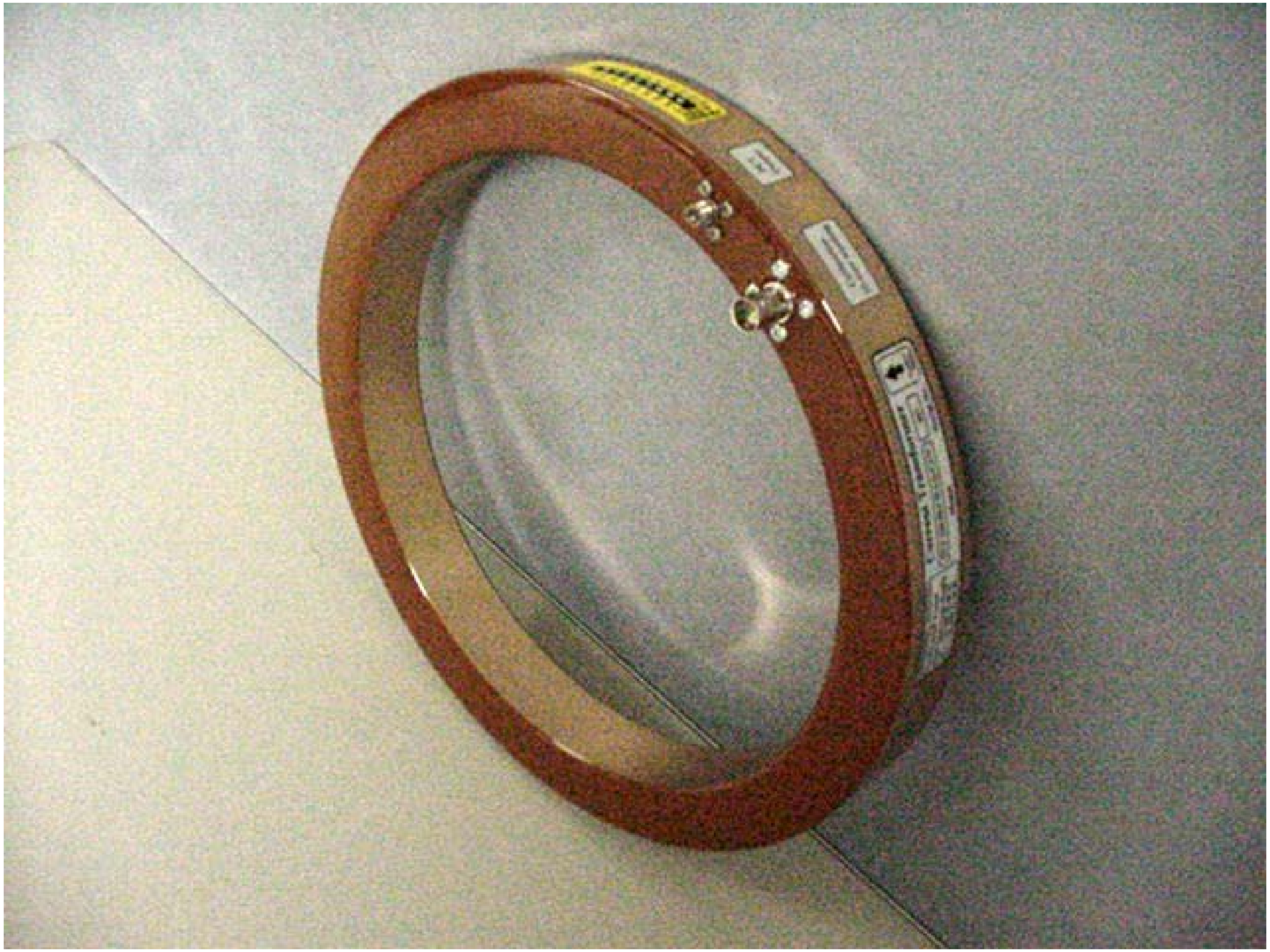
Main Screen Local PC

Shows wire scanner Current for all three channels at local PC. Data also to remote system. This data taken with B.I.T. signals.



Beam Current Monitor

Big connector = Calibration, SMA connector= signal



BCM Requirements

From SNS Diagnostics AP Requirements (03/01)

- MEBT to HEBT 0.3 - 1000 us,
  - 15 to 52mA
  - Accuracy < 1% of FSR
  - Resolution 0.1% of FSR
  - Detail within mini-pulse- available on demand
- Ring to RTBT 5e10 to 2e14 Protons
  - 0.015A to 100A
  - Accuracy < 1% of FSR
  - Resolution 0.1% of FSR (relaxed to 0.5% for gain steps compromise)
  - Turn-by-turn data- available on demand

Interpretation of requirements

Beam Current Monitor Distribution

LOCATION	DIAM.	NUMBER OF BCMS
Front End	5.5cm ID 13.5cm OD	2
Linac	2.5cm,3.0cm,8cm* ID	DTL=6 CCL=2 SCL=1
HEBT	13cm ID	5
Ring	22cm ID	1
RTBT	22cm ID	5

* not finalized

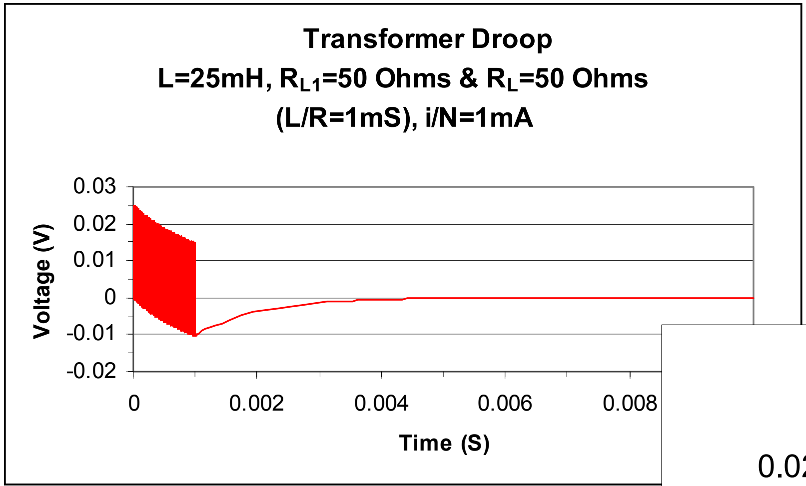
Detectors:

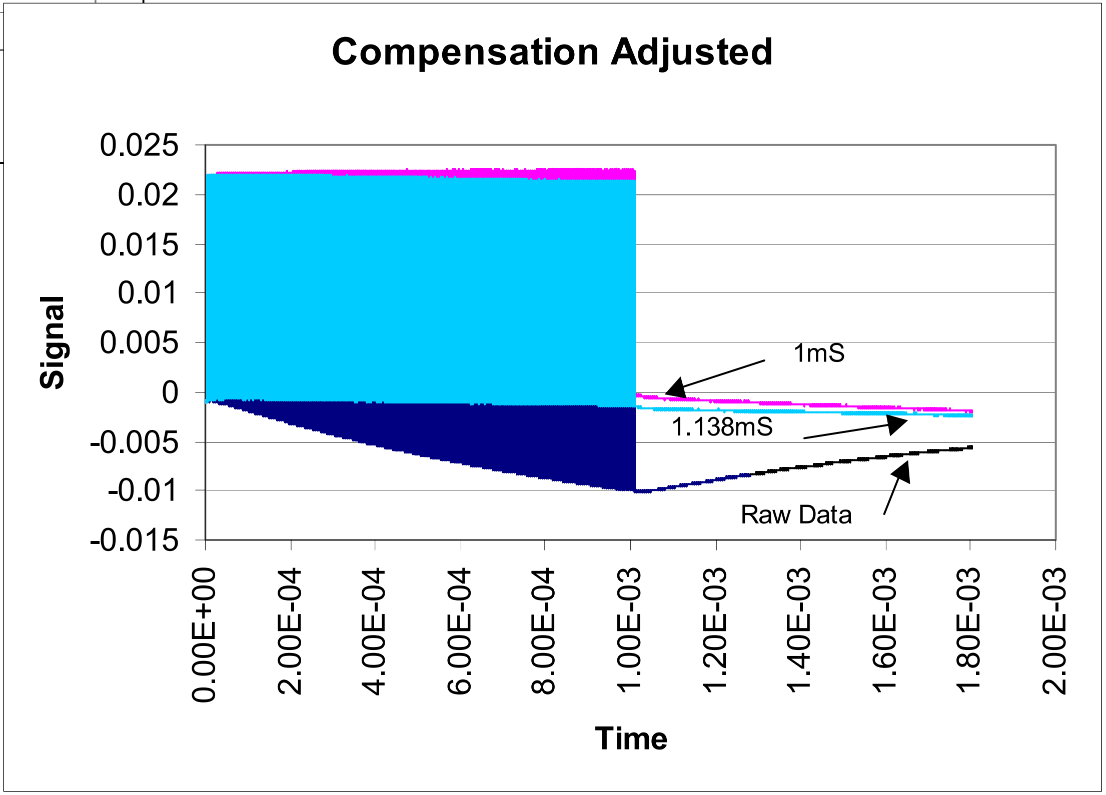
A standard Bergoz FCT (Fast Current Transformer) has been selected for this application. It provides a 50 turn output winding developing 0.5 Volts per Amp into a 50 Ohm load. This FCT will have 1ns rise time and a droop of 0.1% per microsecond making it suitable for the FBCM application. To achieve the low droop for the average beam current measurements, digital droop compensation will be employed in the electronics. To achieve a 1000 to 1 improvement in droop, the time constant of the transformer must be measured to an accuracy of about 0.1%. It is proposed to make measurements during the transformer recovery time between macro-pulses. This recovery signal will be analyzed by an exponential fitting routine to determine the transformer time constant. Numerous measurements can be averaged to provide an estimate within 0.1%. In addition, this transformer will include a second winding with 10 turns to act as a calibration winding. The calibration winding will be electrically isolated from the output winding permitting isolation of grounds.

Electronics

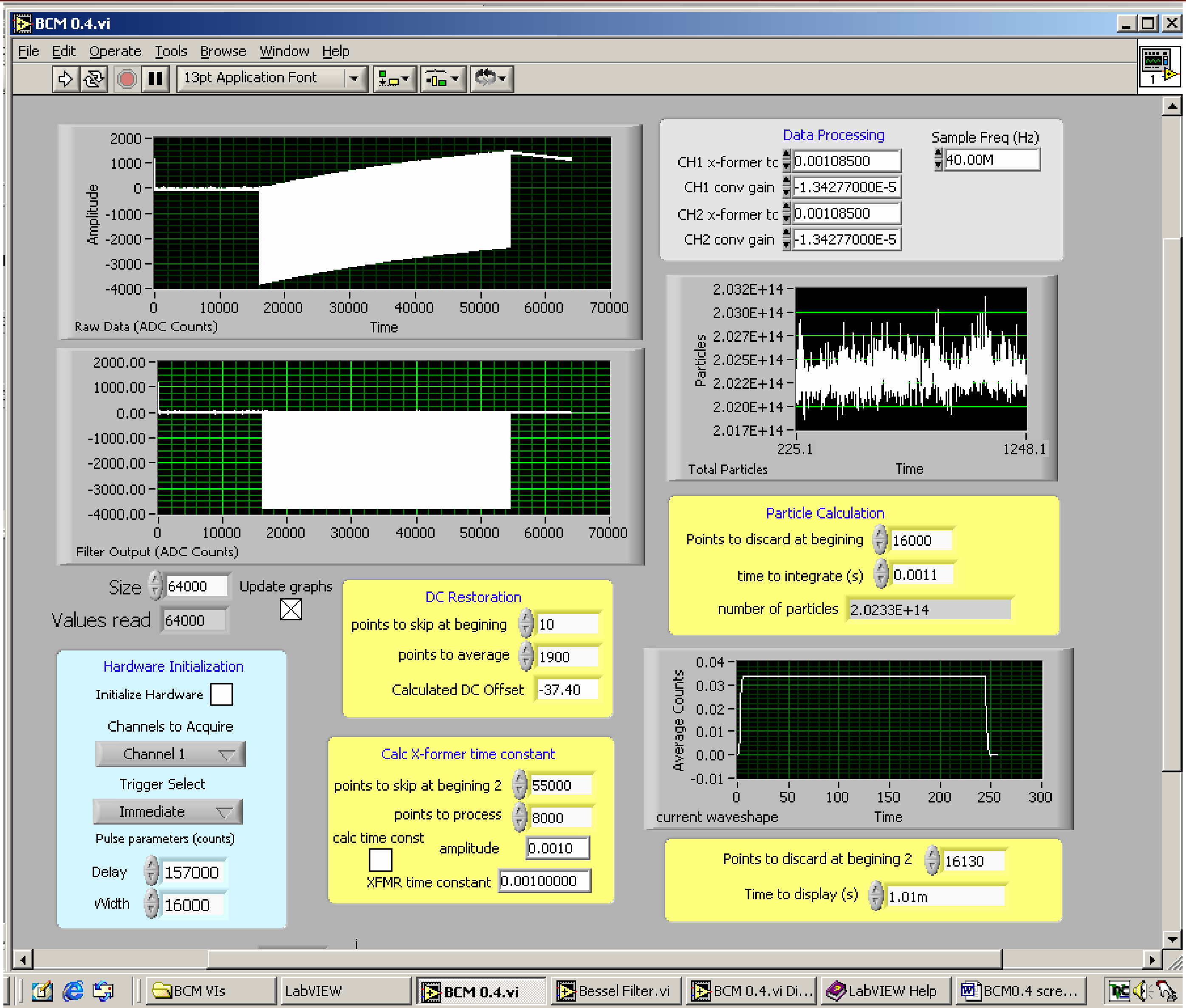
To properly compensate the transformer droop, baseline restoration is necessary and will be accomplished digitally. The signal will be digitized with an 80MSPS ADC (AD6645-80). The analog output to the digitizer will also be available for direct viewing if desired. Adjustable gain will be provided to accommodate the wide dynamic range of the signal (1000 to 1). This will be achieved by providing multiple paths for the signal with different gain in each. All of the paths will be summed, and selection will be made by switching an amplifier equipped for disabled operation (OPA680) to an "OFF" state. These amplifiers switch in about 100ns permitting gain changes during the "gap" time. In this way it will be possible to change gain with no loss of turn information. The digital processing will average the signal prior to the beam pulse to determine the DC offset. This will be subtracted from all digitized data to remove the offset. The droop compensation will employ an IIR filter that provides a zero and a pole. The zero will be set to cancel the lower corner frequency of the transformer and a new corner frequency of 0.159Hz (1 second time constant) will be established to set the droop to 0.1%/ms. The current will be integrated digitally. An ADC running at 64 times the revolution frequency will read the output signal. The analog signal will also be available to display the current stacking.

Droop in Current Transformer Signals





Screen Dump BCM0.4 (1-17-02)



Bandwidth Considerations-1

- The system bandwidth has
  been set to 7MHz as a compromise in noise, response characteristics,
  recovery to < 0.1% during the "gap" time, and anti-aliasing issues.

Bandwidth Considerations-2

- **Chopper Edges (10nS rise time)**
  - Requires >100MHz
- **Mini&Macro-pulse Ring general shape analysis (50nS rise time)**
  - Requires >7MHz
  - Select Gaussian response for transient characteristic to minimize overshoot
- **Settling Time**
  - Response to settle within the 300ns “gap” time (7 MHz filter settles in < 150ns)
- **Resolution**
  - Requires an analysis of noise (7MHz estimate is about 0.1% of 1/2 scale)

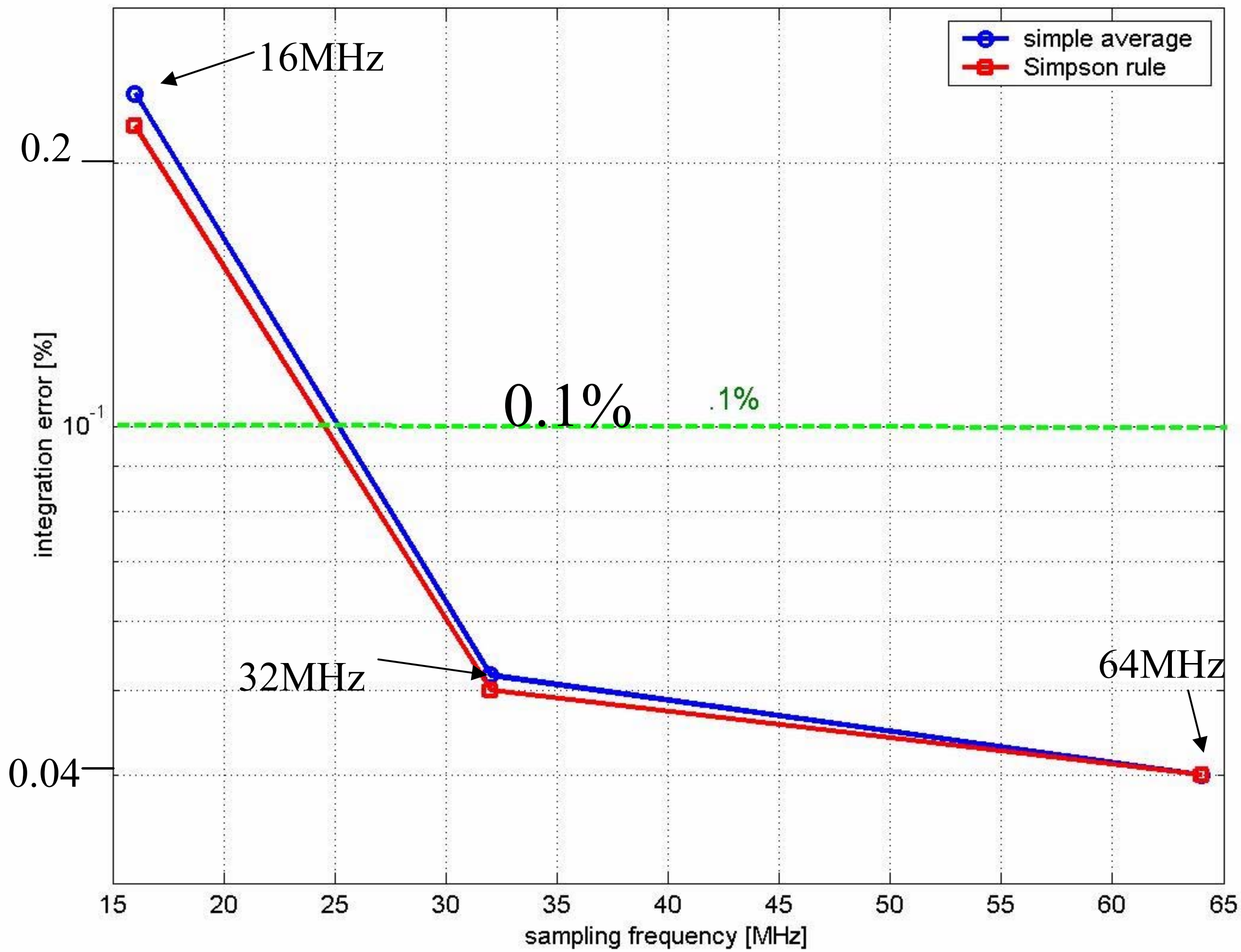
Bandwidth Considerations-3

- **Anti-aliasing**
  - A 5 Pole 7MHz Gaussian filter provides about 43dB attenuation at 34MHz.
  - Adding an additional 5 Pole 17MHz 0.01dB Chebyshev filter will provide an additional 37dB attenuation at 34MHz.
    - Total attenuation at 34MHz is 77dB, an additional -6dB (two stages) for band limited amplifiers yields 83dB attenuation (>13 bits, 1.2LSB).
    - The variable gain amplifier has a 35MHz bandwidth, adding a band-limited summer stage, or filter driver stage provides the necessary additional attenuation with minor pulse overshoot (<5%), and bandwidth shrinkage.
  - Digitizer aliasing held to better than -80dB at Nyquist (0.007%).

Sampling Frequency Considerations

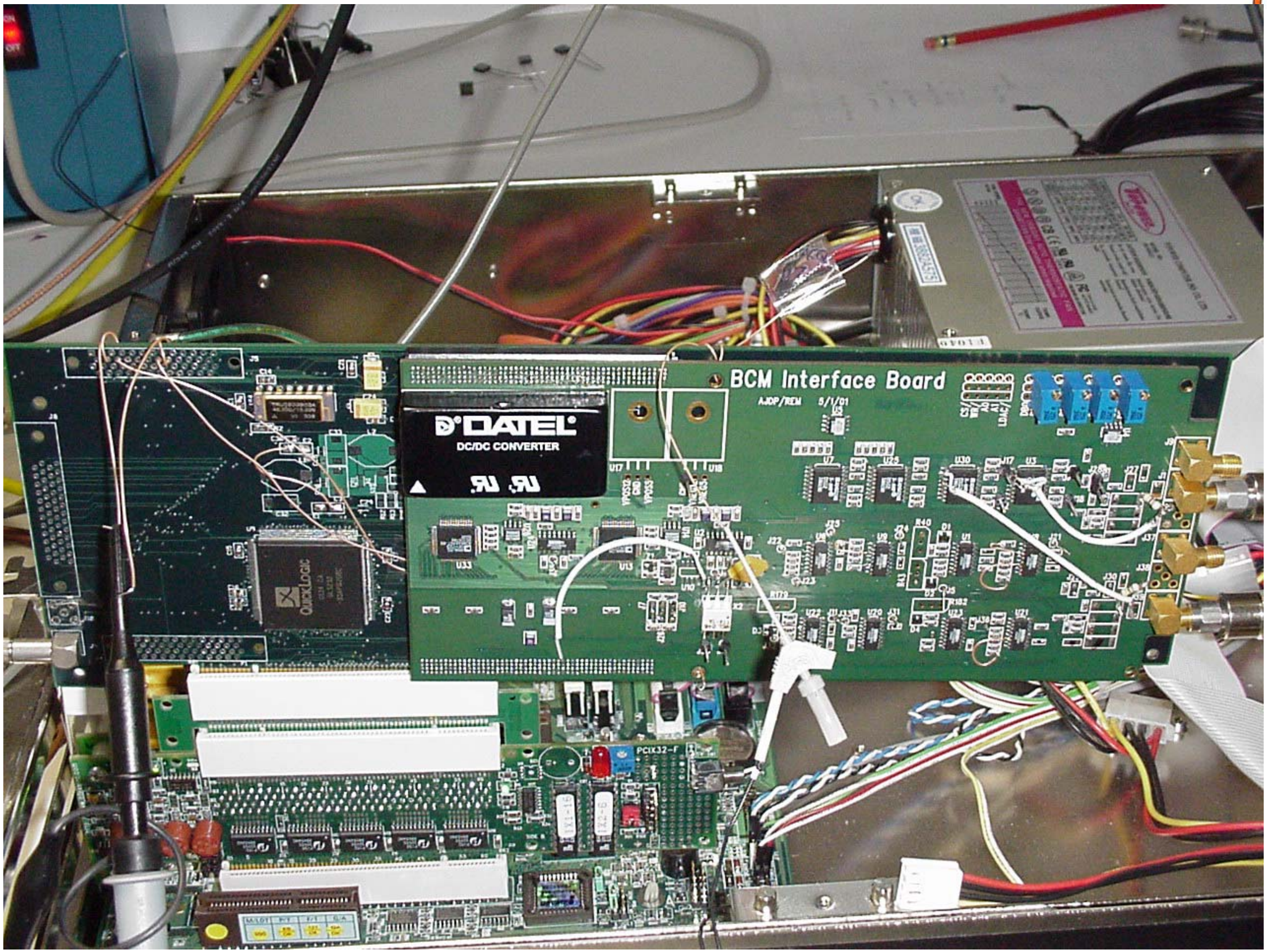
- **The earlier discussion of anti-aliasing assumed a near 70MHz sampling rate**
- **Calculation of charge involves an integration of the current signal. An analysis of integration errors shows one requires a minimum of 25MHz sampling rate to achieve 0.1% accuracy.**
- **It is desirable to be synchronized with the revolution frequency so that samples are nicely related to mini-pulses, simplifying software algorithms.**
  - Reference available is 16*F_{rev} (16.9MHz)
  - Therefore, convenient multiples are 33.8MHz or 67.7MHz
  - AD6645 is available in 80MSPS or 105MSPS 14 Bit ADC versions (pin compatible with AD6644)

Integration Accuracy for Charge Calculation

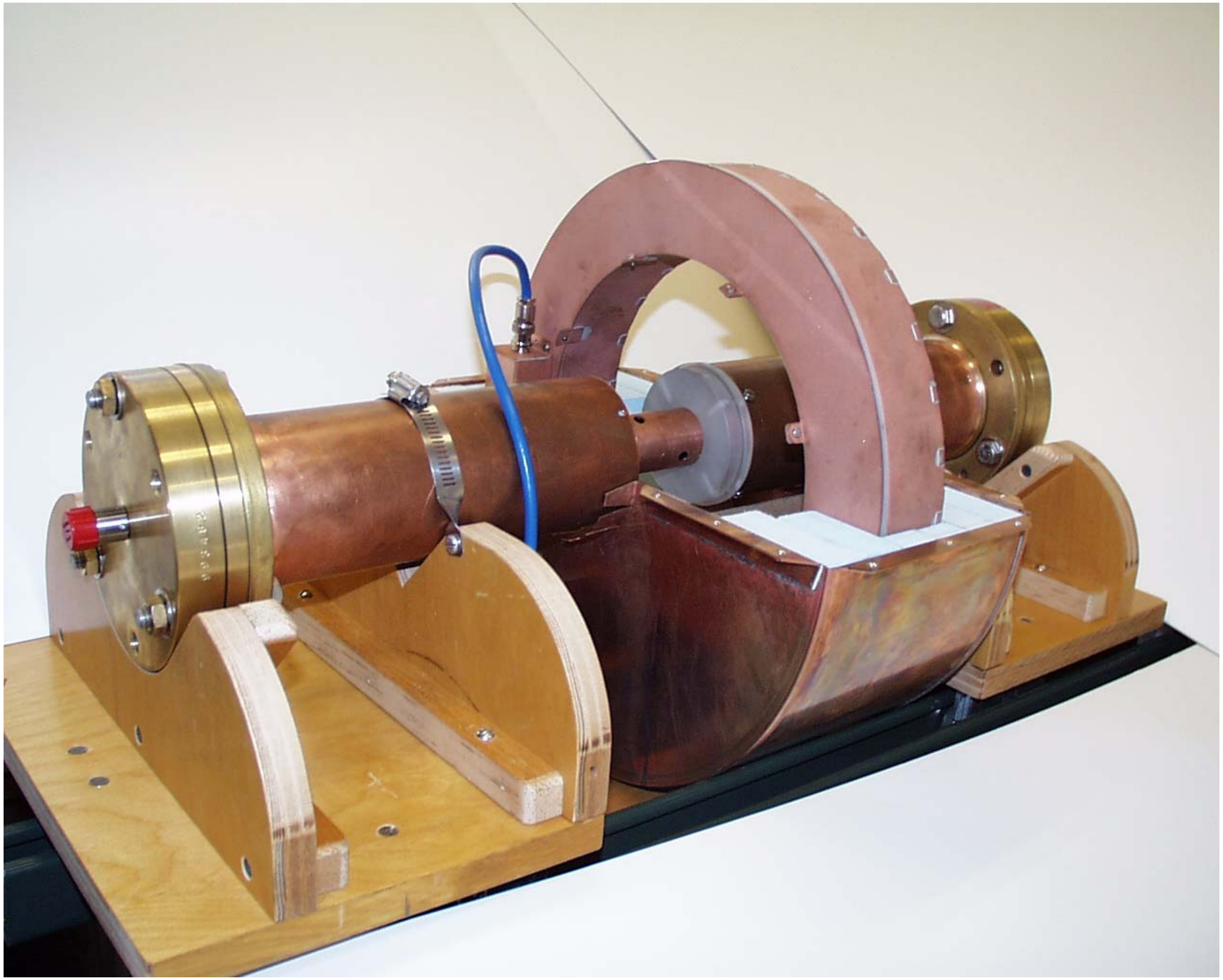


Courtesy of Alexander Aleksandrov

Prototype Board Under Test at BNL 12-21-01



BCM Testing Fixture

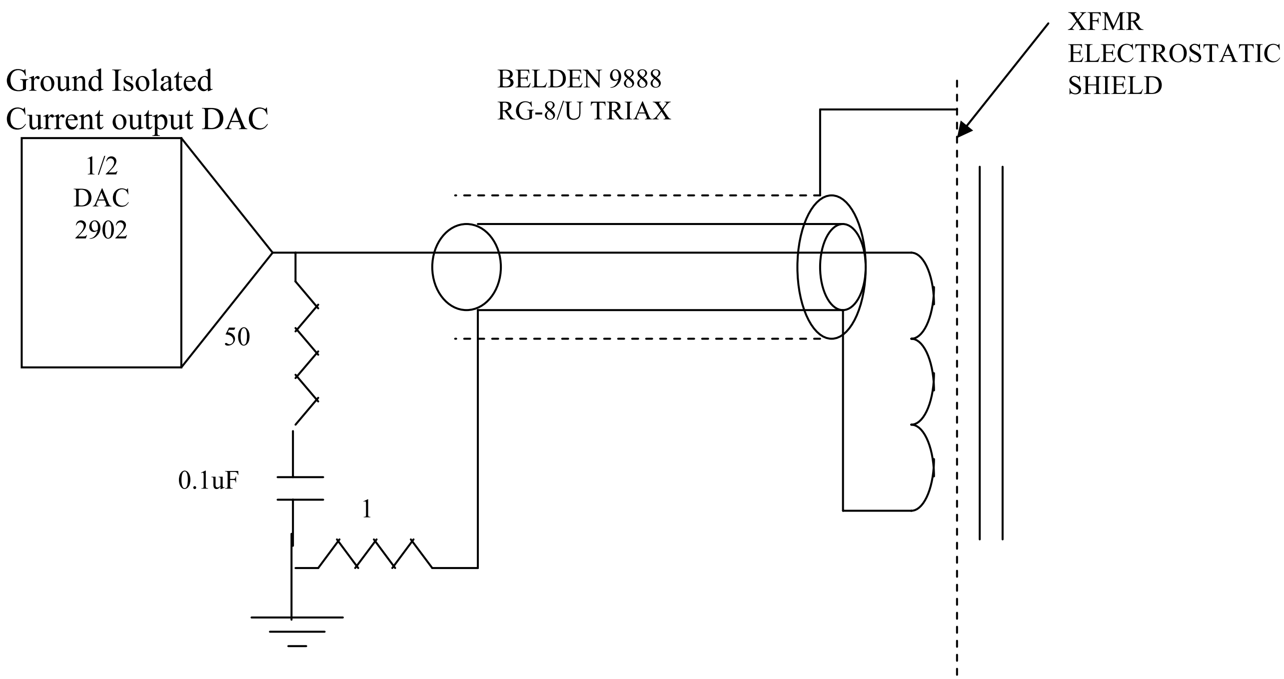


CALIBRATION

– Each FCT has a built in 10 turn calibration coil. Allows for calibration (a sample transformer passes a 700ns pulse with 50ns rise time).

– Bergoz has designed the 10 turn calibration coil for best coupling, and the ability to simulate large currents.

Calibrator



Ground Isolated
Current output DAC
1/2
DAC
2902
BELDEN 9888
RG-8/U TRIAX
XFMR
ELECTROSTATIC
SHIELD
50
0.1uF
1

Calibrator Requirements

- **Remotely controlled**
- **Provide a 50 Ohm termination for the calibration winding**
- **Current output DAC with appropriate termination**
- **Provide a verifiable current pulse**
  - Use a current output DAC to a 50 Ohm load
  - Measure open circuit voltage and short circuit current off-line to calibrate the calibrator.
  - Use Thevenin Equivalent to calculate current applied.
  - Monitor output current as a back-up

Successful Implementation of all SNS Diagnostics at Berkeley

Jan 02	Feb 02	March 02	April 02	May 02

construction

deliveries complete

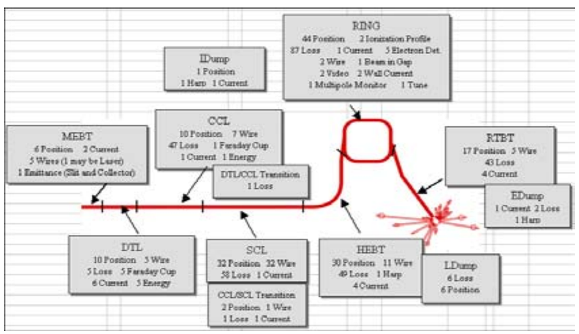
RFQ: Emittance commissioning

MEBT: **installation**

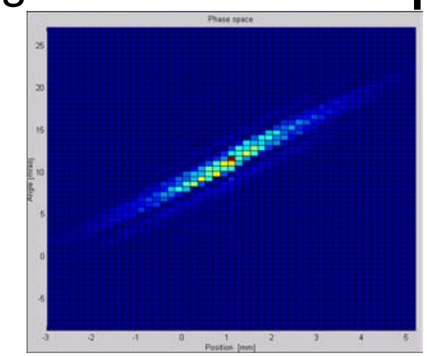
MEBT: 1 week expert visit **integration**

MEBT: 1 week expert visit **commissioning**

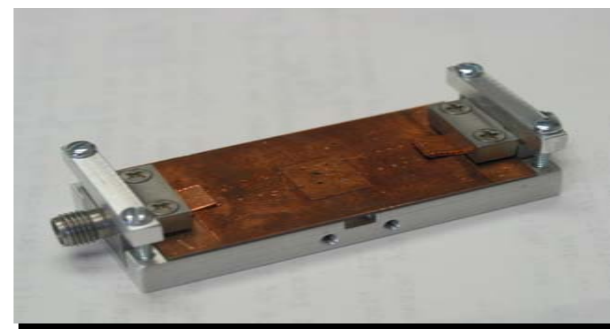
handoff



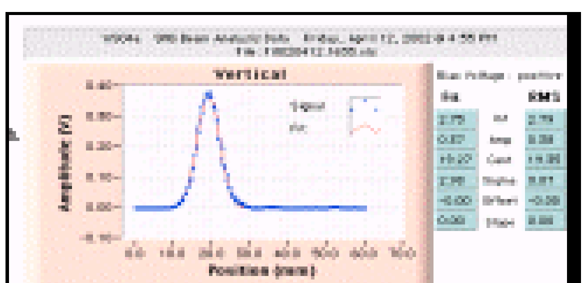
1. Design information:
names, locations, …



2. Emittance Scanner



3. Fast Faraday Cup
modeling,design and Implementation



4. Wire Scanners:
Advanced Data Analysis